



US009914545B2

(12) **United States Patent**  
**Lents et al.**

(10) **Patent No.:** **US 9,914,545 B2**  
(45) **Date of Patent:** **Mar. 13, 2018**

(54) **AIRCRAFT HEAT EXCHANGE SYSTEM INCLUDING A THERMOELECTRIC DEVICE**

USPC ..... 62/3.3, 3.61  
See application file for complete search history.

(71) Applicant: **Hamilton Sundstrand Corporation**,  
Charlotte, NC (US)

(56) **References Cited**

(72) Inventors: **Charles E. Lents**, Amston, CT (US);  
**William E. Rhoden**, Glastonbury, CT (US)

U.S. PATENT DOCUMENTS

(73) Assignee: **HAMILTON SUNDSTRAND CORPORATION**, Charlotte, NC (US)

4,505,124	A	3/1985	Mayer	
5,584,183	A	12/1996	Wright et al.	
7,779,811	B1	8/2010	Mailander et al.	
8,424,285	B2	4/2013	Veilleux, Jr.	
2009/0000310	A1	1/2009	Bell	
2010/0011781	A1*	1/2010	Lents	B64D 13/00 62/3.7
2010/0313591	A1*	12/2010	Lents	F02C 7/10 62/259.2

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 97 days.

(Continued)

(21) Appl. No.: **14/973,177**

FOREIGN PATENT DOCUMENTS

(22) Filed: **Dec. 17, 2015**

EP	1902950	A1	3/2008
EP	2147860	A2	1/2010

(65) **Prior Publication Data**

(Continued)

US 2017/0021938 A1 Jan. 26, 2017

**Related U.S. Application Data**

OTHER PUBLICATIONS

(63) Continuation-in-part of application No. 14/808,523, filed on Jul. 24, 2015.

European Search Report for Application No. 16180964.5-1754, dated Oct. 28, 2016, 7 pages.

(Continued)

(51) **Int. Cl.**  
**B64D 37/00** (2006.01)  
**B64D 37/34** (2006.01)  
**F02C 7/224** (2006.01)

*Primary Examiner* — Mohammad M Ali  
(74) *Attorney, Agent, or Firm* — Cantor Colburn LLP

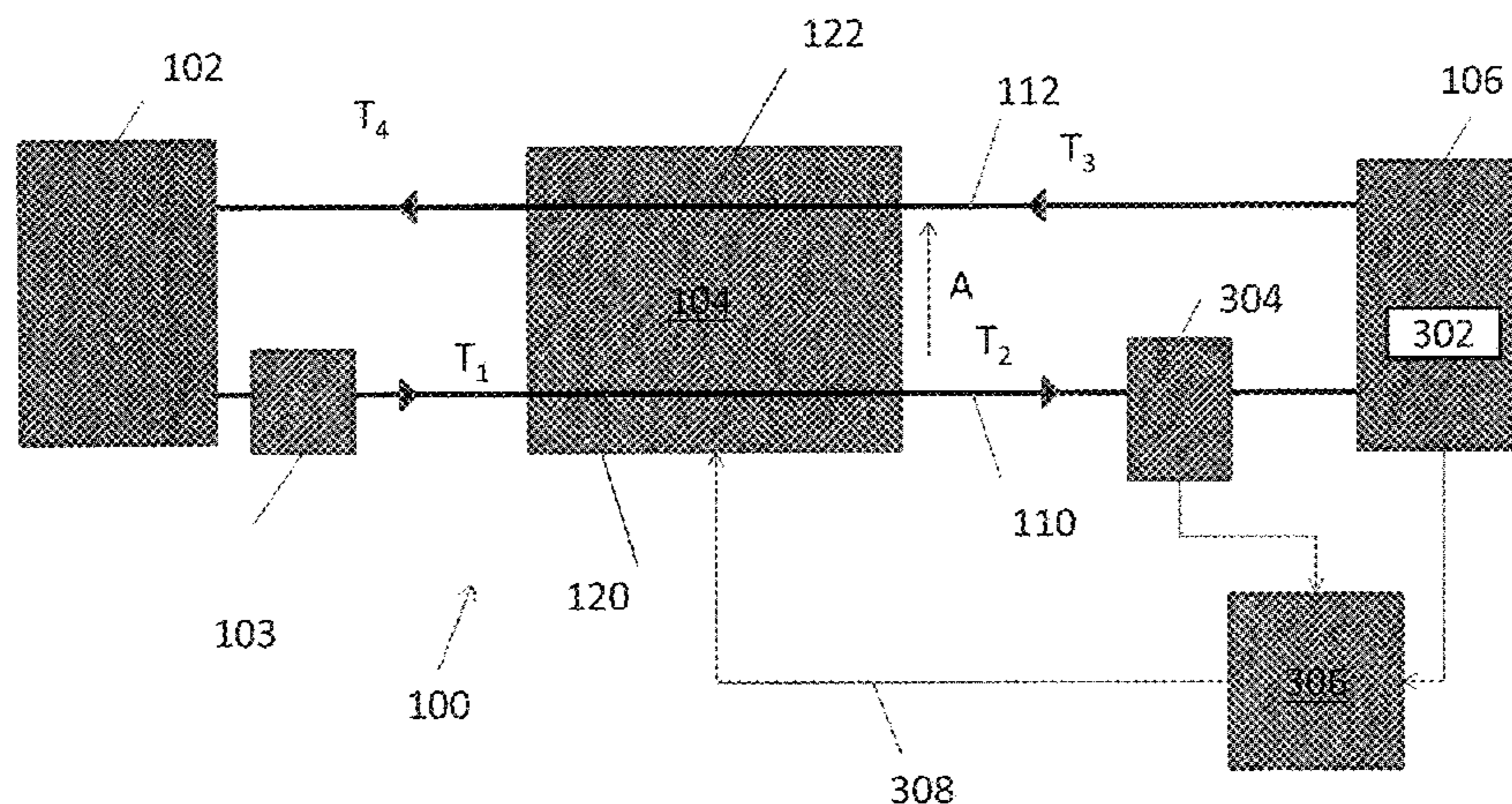
(52) **U.S. Cl.**  
CPC ..... **B64D 37/005** (2013.01); **F02C 7/224** (2013.01); **B64D 37/34** (2013.01)

(57) **ABSTRACT**

(58) **Field of Classification Search**  
CPC ..... B64D 37/005; B64D 37/34; B64D 37/02; F02C 7/222; F02C 9/00; H01L 35/30; H01L 35/28; B60H 1/00478; F25B 21/04; F25B 2321/021; F25B 2321/0252; F25B 2600/07; F25B 21/02; H05K 7/20272; H05K 7/20281

A heat exchange system for an aircraft includes an aircraft controller for controlling an operation of an aircraft, a thermoelectric device having a low temperature side and a high temperature side. Heat is transferred away from the inlet line to the outlet line through the thermoelectric device when a predetermined condition is met.

**13 Claims, 6 Drawing Sheets**



(56)

**References Cited**

U.S. PATENT DOCUMENTS

2012/0095661 A1 4/2012 Roy et al.  
2012/0095662 A1 4/2012 Roy et al.  
2012/0095663 A1 4/2012 Roy et al.  
2015/0233605 A1 8/2015 Bernhardt  
2017/0027082 A1 1/2017 Rhoden et al.

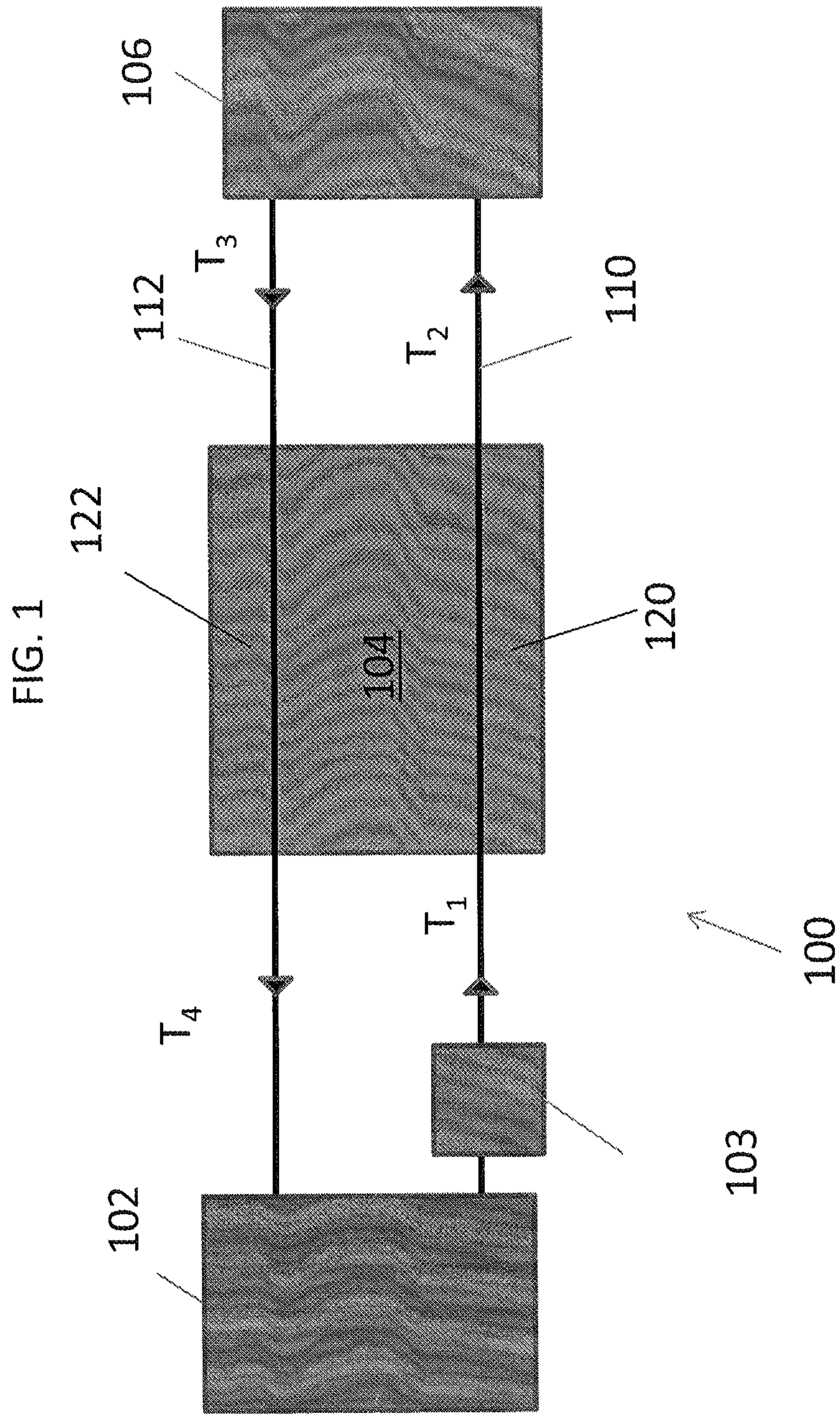
FOREIGN PATENT DOCUMENTS

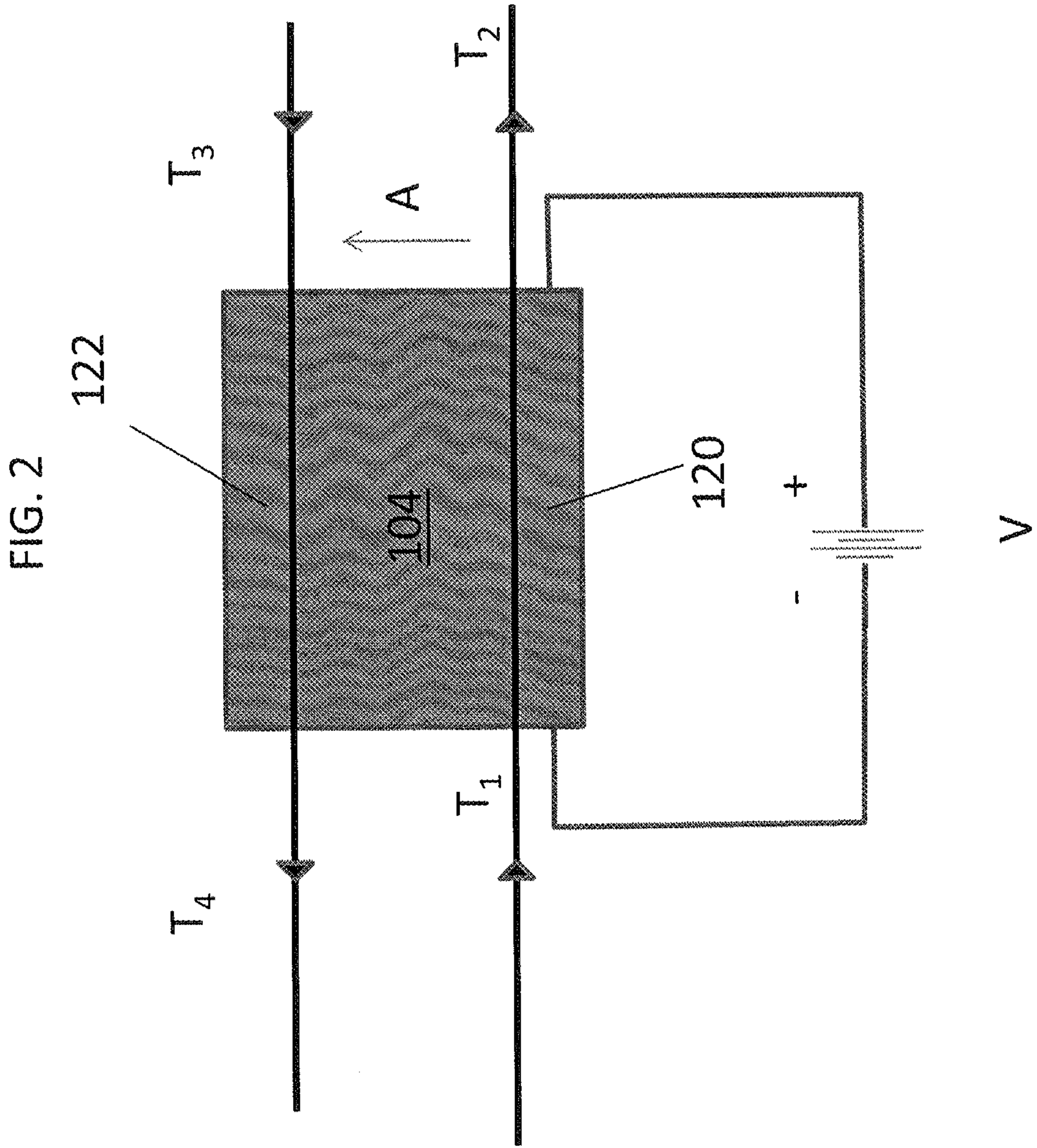
EP 2273088 A1 1/2011  
EP 2441938 A1 4/2012

OTHER PUBLICATIONS

European Search Report for Application No. 16204835.9-1754,  
dated May 15, 2017, 9 Pages.

\* cited by examiner





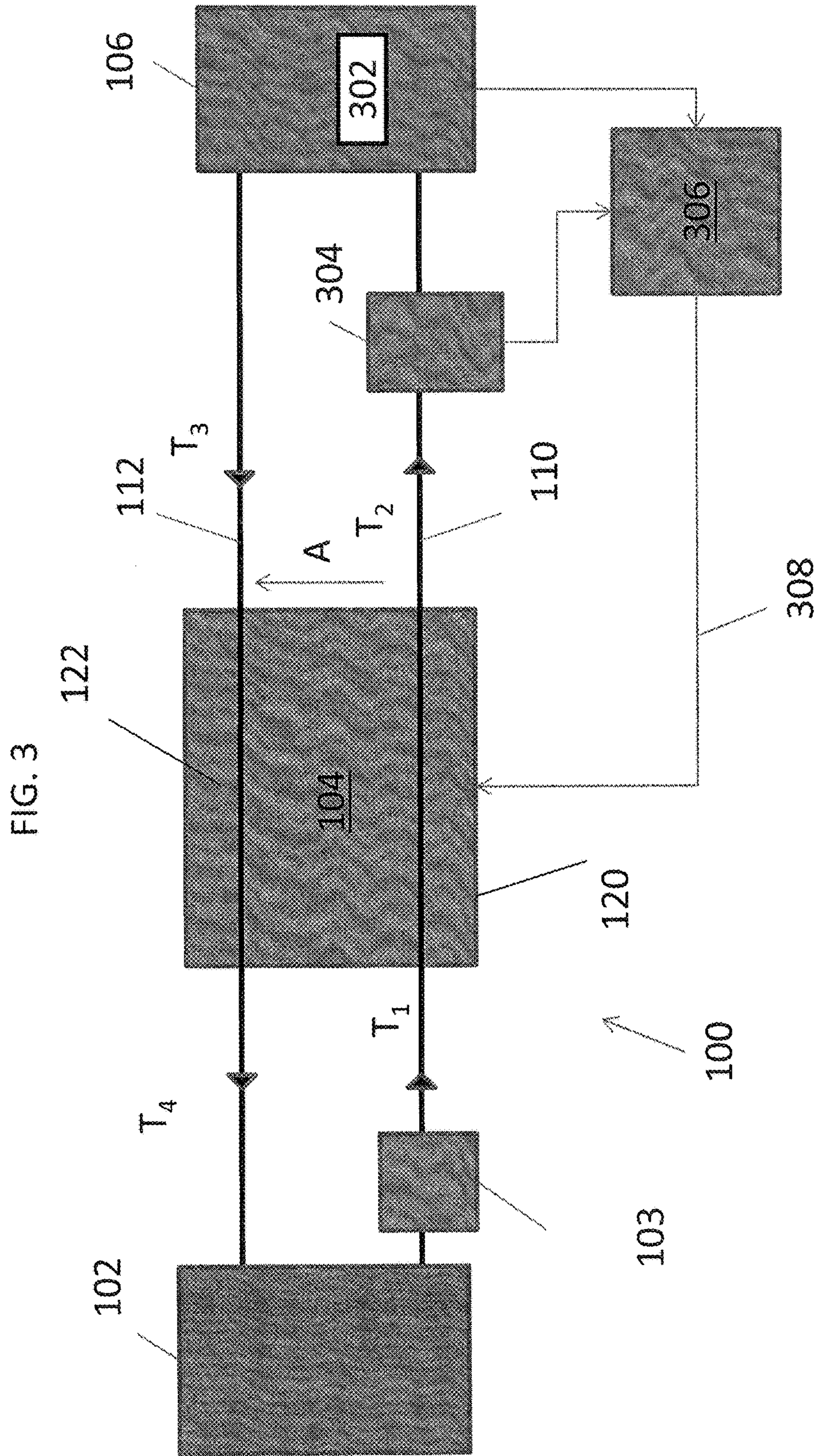


FIG. 4

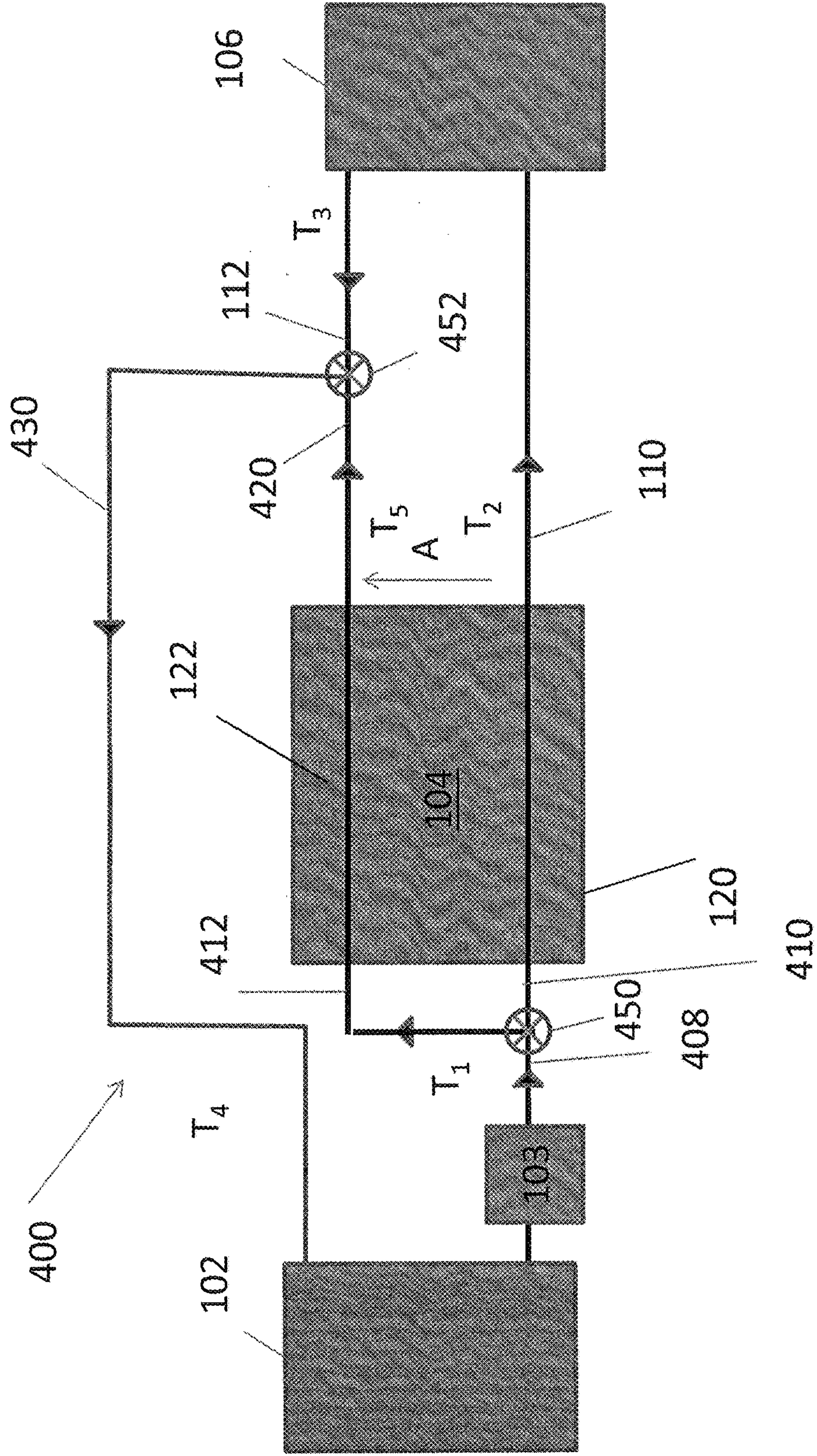


FIG. 5

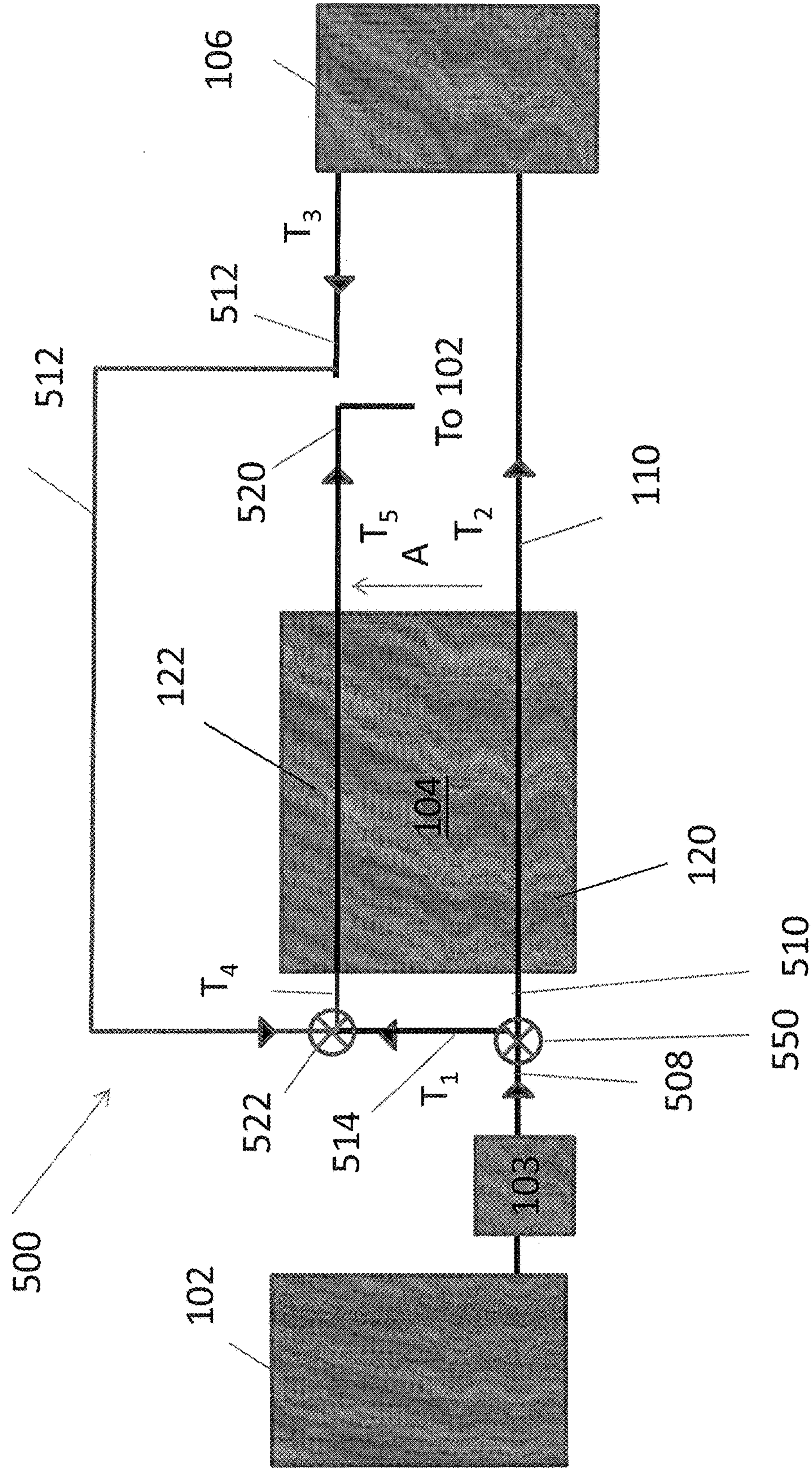
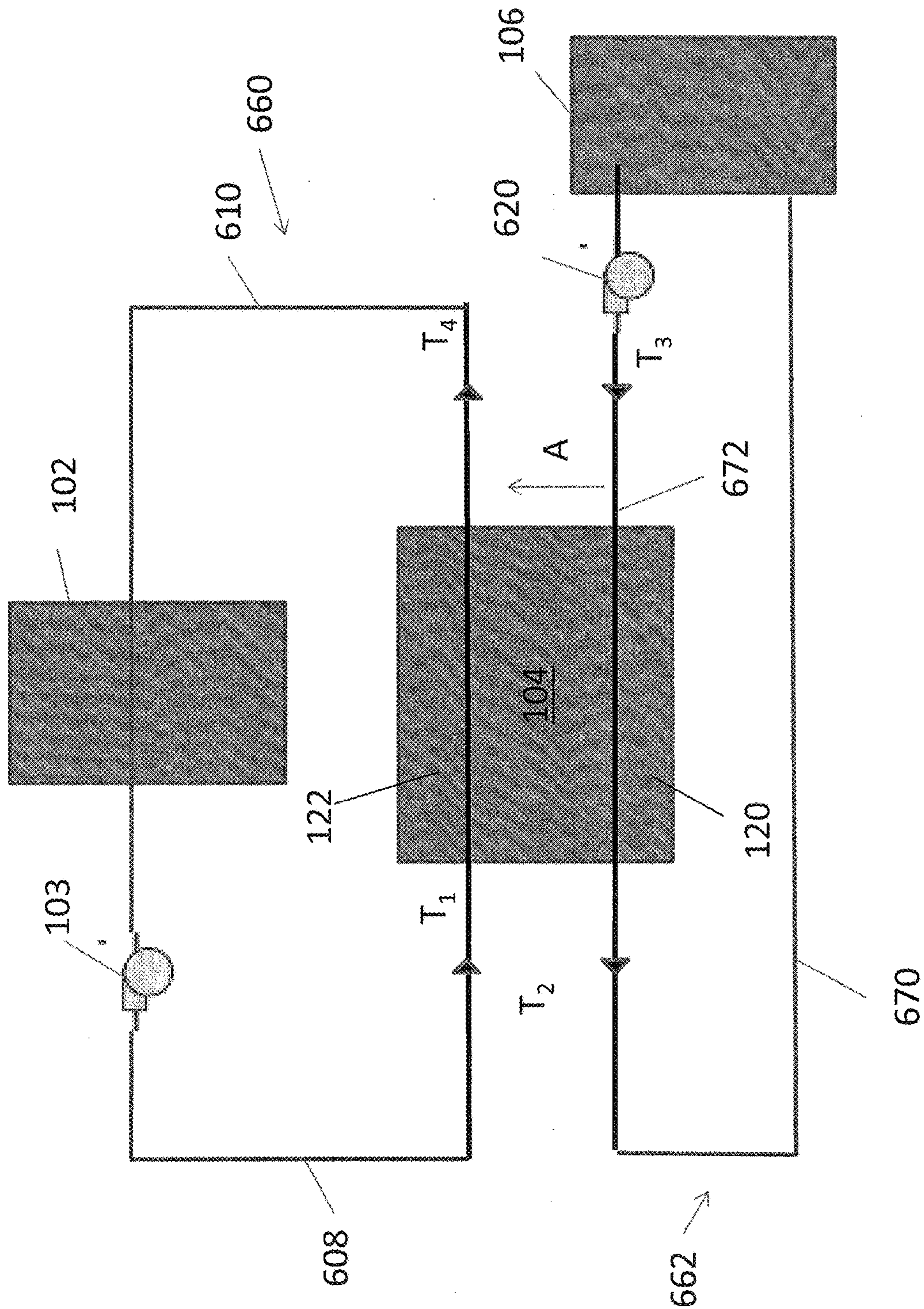


Figure 6





1

## AIRCRAFT HEAT EXCHANGE SYSTEM INCLUDING A THERMOELECTRIC DEVICE

### CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part application of U.S. Ser. No. 14/808,523 filed Jul. 24, 2015, the contents of which are incorporated by reference herein in their entirety.

### BACKGROUND OF THE INVENTION

The present disclosure relates to a heat exchanger for an aircraft and, in particular, to using a thermoelectric device to regulate the heat of fuel used to cool a controller of the aircraft.

An aircraft has a number of electronic controllers used to control operation of the aircraft. One such controller manages the function of the aircraft engines and is commonly known as a Full Authority Digital Engine Control or FADEC. The FADEC is generally installed in an environment of the aircraft susceptible to both very high temperatures and very low temperatures. For example, the FADEC may be installed in the engine bay where large amounts of heat are generated during flight conditions. In these conditions, the FADEC requires a substantial amount of cooling to regulate its operating temperature. When the aircraft is not in flight, however, the engine bay may be extremely cold when ambient air temperature is low. At these conditions, the FADEC requires very little, if any, cooling.

The FADEC, like many aircraft controls, is composed of electronic components that require moderate and uniform temperatures for optimal operation. The large temperature swings experienced by the FADEC is not conducive to the best performance of these temperature sensitive components. While there are electronic components that are capable of performing at the extreme temperature conditions of the aircraft, these components are generally very expensive and have relatively low performance (memory, process, reliability, or speed) compared to most modern electronics.

A need therefore exists for an assembly and technique that maintains the electronics of an aircraft controller within their designed operating temperatures.

### SUMMARY OF THE INVENTION

According to one embodiment, a heat exchange system for an aircraft is disclosed. The system of this embodiment includes an aircraft controller for controlling an operation of an aircraft, a thermoelectric device having a low temperature side and a high temperature side and a tank output line that carries fluid from a fuel tank to inputs of the low temperature side and the high temperature side. The system also includes an aircraft controller inlet line that carries fluid from an output of the low temperature side of the thermoelectric device to the aircraft controller, a high temperature side output line that exits the high temperature side of the thermoelectric device and an outlet line that carries the fluid away from the aircraft controller. Further, this system includes a first valve that causes fluid in the output line and the high temperature side output line to mix to form a mixed fluid and a return line that returns the mixed fluid from an output of the first valve to the fuel tank. In this system, wherein heat is transferred away from fuel at the input of the low temperature side to the fuel at the input of the high temperature side.

2

According to another embodiment, a heat exchange system for an aircraft is disclosed. In this embodiment, the system includes an aircraft controller for controlling an operation of an aircraft, a thermoelectric device having a low temperature side and a high temperature side and a low temperature side input line connected to an input of the low temperature side. The system also includes a high temperature side input line connected to an input of the high temperature side, an tank output line that carries fluid from a fuel tank to both the low temperature side input line and the high temperature side input line and an aircraft controller inlet line that carries fluid from an output of the low temperature side of the thermoelectric device to the aircraft controller. Further, this system includes an outlet line that carries the fluid away from the aircraft controller, a first valve that causes fluid in the output line and the high temperature side input line to mix to form a mixed fluid and enter the thermoelectric device and a high temperature side output line that exits the high temperature side of the thermoelectric device. In this embodiment, heat is transferred away from fuel at the input of the low temperature side to the fuel at the input of the high temperature side.

According to yet another embodiment, a heat exchange system for an aircraft is disclosed. In this embodiment, the system includes an aircraft controller for controlling an operation of an aircraft, a thermoelectric device having a low temperature side and a high temperature side and an aircraft controller loop. The loop includes a first pump that circulates fluid through the low temperature side and the aircraft controller and a fuel loop comprising: a second pump that circulates fuel from a fuel tank and through the high temperature side. In this embodiment, heat is transferred away from fluid in the aircraft controller loop passing through the low temperature side to fuel in the fuel loop passing through the high temperature side.

Additional features and advantages are realized through the techniques of the present disclosure. Other embodiments and aspects of the disclosure are described in detail herein. For a better understanding of the disclosure with the advantages and the features, refer to the description and to the drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

The subject matter which is regarded as the invention is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features, and advantages of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 shows a high level block diagram of heat exchange system where engine fuel is used as a cooling liquid to cool a FADEC;

FIG. 2 shows a more detailed depiction of an example of a thermoelectric device that may be utilized in one embodiment;

FIG. 3 shows a more detailed version of a system according to one embodiment;

FIG. 4 shows a version of a system according to one embodiment;

FIG. 5 shows a version of a system according to another embodiment;

and

FIG. 6 shows a version of a system according to yet another embodiment.

DETAILED DESCRIPTION OF THE  
INVENTION

Embodiments described herein to closed loop cooling system for a FADEC. The FADEC may be part of an aircraft and, as such, embodiments disclosed herein may be implanted on an aircraft. The system may utilize thermo-electric (TE) device positioned between the inbound and outbound fuel lines providing cooling fuel to the FADEC. While not required, in one embodiment, the TE device is a thin-film super lattice device. The TE device, when powered, “pumps” heat from the inbound fuel line and provides that heat to the hot, outbound fuel line. According to one embodiment, the TE device is sized to handle fuel temperatures up to 190° F. at flow rates currently used for FADEC cooling. Closed loop control is achieved when fuel temperature sensing is applied to the inbound flow. When temperatures exceed inbound limits, a controller adjusts power provided to the TE device to effect cooling of the fuel to keep inbound fuel temperatures at the desired level.

FIG. 1 shows a high level block diagram of heat exchange system 100 where engine fuel is used as a cooling liquid to cool a FADEC. Most generally, the system includes a fuel tank 102, one or more pump (shown as pump 103), a TE device 104 and electronics to be cooled 106. In the following discussion the electronics may be referred to as a FADEC but it shall be understood that other electronics or even other non-electronic devices may be cooled in the manner disclosed herein. As such, while FADEC is used as a description, unless specifically required, the electronics to be cooled 106 are not limited to a FADEC.

Engine fuel is stored in a reservoir or fuel tank 102. The tank 102 may be a primary fuel tank used for all engines or an individual tank used for a single engine. Further, the tank 102 may be a portion of a larger tank. A pump 103 is provided that can pump fuel out of the tank 102. This pump 103 may be a single pump or may include more than one pump. Regardless of the configuration, the pump 103 causes fuel from the tank 102 to be provided through an input line 110 to the FADEC 106. The input line 110 passes through a low temperature heat source side 120 (referred to as “low temperature side” hereinafter) of the TE device 104 before being provided to the FADEC 106. The fuel in the input line 110 passes through, around or near the FADEC 106 such that heat from the FADEC 106 is transferred to the fuel. The fuel then returns to the fuel tank 102 via return line 112. Before returning the fuel tank 102 via return line 112, the fuel passes through the high temperature heat sink side 122 (referred to as “high temperature side”) hereinafter of the TE device 104. In general, to the extent that the TE device removed heat from the fuel as it passed through the low temperature side 120, that heat is at least partially transferred to the fuel in the return line 112 as it passes through the high temperature heat sink side 122 of the TE device 104.

In operation, fuel enters the lower temperature side 120 of the TE device 104 at a first temperature  $T_1$ . When operating, the energy (heat) is removed from the fuel by the TE device 104 such that it leaves the TE device at a second, lower temperature  $T_2$ . The fuel then enters the FADEC 106 where it has heat transferred to it and leaves the FADEC at  $T_3$ . It is assumed that in operation,  $T_3$  is greater than  $T_2$ .

As mentioned above, as the fuel in the return line 112 is passed through the high temperature side 122 of the TE device 104, heat removed from the fuel at the low temperature side 120 is added to the fuel such that it exits the TE device 104 at an even higher temperature  $T_4$ . That is,  $T_4$  is greater than  $T_3$  when the TE device is operating.

In one embodiment, the TE device 104 may be formed such that that application of a voltage and current causes heat in one location to be moved to another location. With reference to FIG. 2, application of a voltage V and current to the low temperature side causes heat from to move from one side of the TE device to the other as indicated by arrow A. The direction of the travel is based on the polarity of the voltage and the rate is based on the magnitude of the current. As shown, the direction of heat travel is against the temperature gradient.

As discussed above, and now with reference to FIG. 3, at times the TE device 104 may not be operating to remove heat from the input line 110. Such a case may exist when  $T_1$  is sufficiently low to cool the FADEC 106 without having heat removed from it. To that end, in one embodiment, the system 100 may include a temperature sensor 304 that measures the temperature of the fuel in the input line 110 after it exits the TE device 104. Of course, the position of the sensor could be moved such that it is upstream (e.g., closer to the tank 102 than the TE device 104) of the TE device 104 in one embodiment.

In such a system a sensor 302 may also be provided that measures the temperature in or near the FADEC 106. While shown in the FADEC itself, it shall be understood that the sensor need only be able to measure the temperature of the FADEC and does not have to necessarily be within it. Based on the two temperatures, a cooling controller 306 determines how much (if any) heat needs to be removed from the fuel such that  $T_2$  is at a level that may effectively cool the FADEC 106. In one embodiment, the TE device 104 may operate when the temperature of the fluid leaving it is over a predetermined level.

Regardless, the amount of change needed will determine the voltage polarity and current level provided on line 308 to set the rate at which the TE device 104 removes heat from the input line 110. The exact manner in which voltage and current is applied will depend on the type/configuration of the TE device 104 used.

In the above description, certain sensors (e.g. 302, 304) and controllers (306) have been illustrated. These sensors may be included in the following alternative embodiments.

FIG. 4 is high level block diagram of heat exchange system 400 where engine fuel is used as a cooling liquid to cool a FADEC. The system may include any or all pumps and sensors discussed above.

Most generally, the system includes a fuel tank 102, one or more pump (shown as pump 103), a TE device 104 and electronics to be cooled 106.

As above, engine fuel is stored in a reservoir or fuel tank 102. The tank 102 may be a primary fuel tank used for all engines or an individual tank used for a single engine. Further, the tank 102 may be a portion of a larger tank. A pump 103 is provided that can pump fuel out of the tank 102. The pump 103 causes fuel from the tank 102 to be provided through a tank output line 408 to both the low temperature side 120 and the high temperature side 122 of the TE device 104. Tank output 408 splits into low temperature heat source side input line 410 and high temperature heat sink side input line 412. A valve 450 or other element may control flow rate of the fluid in the heat source side input line 410 and heat sink side input line 412. In this embodiment, heat is pumped in direction A such that heat in the heat source side input line 410 is moved to the fluid in the heat sink side input line 412. The fluid leaves the heat source side 120 at a temperature  $T_2$  lower than the inlet temperature  $T_1$  via input line 110 and is provided to the FADEC 106. The fuel in the input line 110 passes through, around or near the FADEC 106 such that

## 5

heat from the FADEC 106 is transferred to the fuel. The fuel then returns to the fuel tank 102 via return line 112. As it returns to the fuel tank 102 via return line 112, the fuel is mixed with fuel output from the heat sink side 122 in heat sink side output line 420 at valve 450. Fuel is then return to the tank 102 via tank return line 430.

In operation, fuel enters the lower temperature heat source side 120 and the high temperature heat sink side 122 of the TE device 104 at a first temperature  $T_1$ . When operating, the energy (heat) is removed from the fuel by the TE device 104 such that it leaves the TE device at a second, lower temperature  $T_2$ . The fuel then enters the FADEC 106 where it has heat transferred to it and leaves the FADEC at  $T_3$ . It is assumed that in operation,  $T_3$  is greater than  $T_2$ .

As mentioned above, the fuel in the return line 112 ( $T_3$ ) is mixed with fuel output from the high temperature heat sink side 122 of the TE device 104 ( $T_5$ ). This fuel in line 122 includes the heat removed from the fuel at the low temperature heat source side 120 and is at temperature  $T_5$ . As this fuel is mixed with the fuel leaving the FADEC 106 in return line 112, that fuel is heated/cooled (depending on operating conditions) to a level that is denoted by  $T_4$ .

In operation,  $T_4 > T_1 > T_3 > T_2$  when the TE device is operating.

FIG. 5 is a high level block diagram of heat exchange system 400 where engine fuel is used as a cooling liquid to cool a FADEC. The system may include any or all pumps and sensors discussed above.

Most generally, the system includes a fuel tank 102, one or more pump (shown as pump 103), a TE device 104 and electronics to be cooled 106.

As above, engine fuel is stored in a reservoir or fuel tank 102. The tank 102 may be a primary fuel tank used for all engines or an individual tank used for a single engine. Further, the tank 102 may be a portion of a larger tank. A pump 103 is provided that can pump fuel out of the tank 102. The pump 103 causes fuel from the tank 102 to be provided through a tank output line 508 to the low temperature heat source side 120 and the fuel line 514. Tank output 508 splits into low temperature heat source side input line 510 and line 514. A valve 550 of other element may control the flow rate of the fluid in the heat source side input line 510 and line 514. In this embodiment, heat is pumped in direction A such that heat in the heat source side input line 510 is moved to the fluid in the heat sink side 122. The fluid leaves the heat source side 120 via input line 510 and is provided to the FADEC 106. The fuel in the input line 510 passes through, around or near the FADEC 106 such that heat from the FADEC 106 is transferred to the fuel. The fuel then exits the FADEC via return line 512. The fuel in return line is then mixed with fuel in the line 514 at valve 552. This mixed temperature fuel at temperature  $T_4$ , where  $T_1 > T_4 > T_3$  is then supplied to the high temperature heat sink side of the TE device 104.

In operation, fuel enters the lower temperature side 120 of the TE device 104 at a first temperature  $T_1$ . When operating, the energy (heat) is removed from the fuel by the TE device 104 such that it leaves the TE device at a second, lower temperature  $T_2$ . The fuel then enters the FADEC 106 where it has heat transferred to it and leaves the FADEC at  $T_3$ .

In this embodiment, fuel in the return line 512 is mixed with fuel in the line 514 at valve 552 and the mixed fuel leaves that valve at temperature  $T_4$ . The fuel that enters the heat sink side 122 receives the heat removed from the heat source side (heating the fuel to temperature  $T_5$ ) and then is returned via output line 420 to tank 102.

## 6

In operation,  $T_5 > T_1 > T_4 > T_3 > T_2$  when the TE device is operating.

FIG. 6 is a high level block diagram of heat exchange system 400 where engine fuel is used as a cooling liquid to cool a FADEC. The system may include any or all pumps and sensors discussed above.

Most generally, the system includes a fuel loop 660 and FADEC loop 662. In this embodiment, fuel in the fuel loop 662 circulates such that it does not mix with the fuel in loop 660.

As above, engine fuel is stored in a reservoir or fuel tank 102. The tank 102 may be a primary fuel tank used for all engines or an individual tank used for a single engine. Further, the tank 102 may be a portion of a larger tank. A pump 103 is provided that can pump fuel out of the tank 102. The pump 103 causes fuel from the tank 102 to be provided through a tank output line 608 to the high temperature heat sink side 122 of the TE device 104. After passing through the high temperature side 122, the fuel is returned to the tank 102 via tank return line 610 to complete the fuel loop 660.

FADEC loop 662 includes FADEC 106 and a second pump 620. The loop 662 is closed. The fluids in the fuel loop 660 and FADEC loop 662 do not mix but heat may be transferred between them via the TE device 104. In one embodiment, fluid at temperature  $T_2$  leaves the TE device 104 via input line 670 and enters the FADEC 106 where it removes heat from the FADEC 106 and returns to the TE device 104 low temperature heat source side 120 via return line 672. The fluid may be pumped by second pump 620 and the location of the second pump can be on either line 670 or 672. The fluid takes heat from the FADEC which is then pumped to the fuel loop 660 as indicated by arrow A. In operation,  $T_4 > T_1 > T_3 > T_2$ .

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one more other features, integers, steps, operations, element components, and/or groups thereof.

While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention.

Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

The invention claimed is:

1. A heat exchange system for an aircraft comprising:
  - an aircraft controller for controlling an operation of an aircraft;
  - a thermoelectric device having a low temperature side and a high temperature side;
  - a tank output line that carries fluid from a fuel tank to inputs of the low temperature side and the high temperature side;

7

an aircraft controller inlet line that carries fluid from an output of the low temperature side of the thermoelectric device to the aircraft controller;

a high temperature side output line that exits the high temperature side of the thermoelectric device;

an outlet line that carries the fluid away from the aircraft controller;

a first valve that causes fluid in the output line and the high temperature side output line to mix to form a mixed fluid; and

a return line that returns the mixed fluid from an output of the first valve to the fuel tank;

wherein heat is transferred away from fuel at the input of the low temperature side to the fuel at the input of the high temperature side.

2. The heat exchange system of claim 1, further comprising:

a second valve that receives the fluid from the an tank output line and provides it to a low temperature input line that carries fluid to the input of the low temperature side and a high pressure input line that carries fluid the input of the high temperature side.

3. The heat exchange system of claim 1, further comprising:

a control unit that provides an electrical signal to the thermoelectric device based on one or both of a temperature of fluid in the aircraft controller inlet line and a temperature of the aircraft controller.

4. The heat exchange system of claim 1, further comprising:

a pump to circulate the fuel from the fuel tank to the aircraft controller and to return the fuel to the fuel tank.

5. The heat exchange system of claim 1, wherein the aircraft controller is a Full Authority Digital Engine Control.

6. A heat exchange system for an aircraft comprising:

an aircraft controller for controlling an operation of an aircraft;

a thermoelectric device having a low temperature side and a high temperature side;

a low temperature side input line connected to an input of the low temperature side;

a high temperature side input line connected to an input of the high temperature side;

a tank output line that carries fluid from a fuel tank to both the low temperature side input line and the high temperature side input line;

an aircraft controller inlet line that carries fluid from an output of the low temperature side of the thermoelectric device to the aircraft controller;

an outlet line that carries the fluid away from the aircraft controller;

8

a first valve that causes fluid in the output line and the high temperature side input line to mix to form a mixed fluid and enter the thermoelectric device; and

a high temperature side output line that exits the high temperature side of the thermoelectric device;

wherein heat is transferred away from fuel at the input of the low temperature side to the fuel at the input of the high temperature side.

7. The heat exchange system of claim 6, further comprising:

a second valve that receives the fluid from the an tank output line and provides it to a low temperature input line that carries fluid to the input of the low temperature side and a high pressure input line that carries fluid through the first valve and to the input of the high temperature side.

8. The heat exchange system of claim 6, further comprising:

a control unit that provides an electrical signal to the thermoelectric device based on one or both of a temperature of fluid in the aircraft controller inlet line and a temperature of the aircraft controller.

9. The heat exchange system of claim 6, further comprising:

a pump to circulate the fuel from the fuel tank to the aircraft controller and to return the fuel to the fuel tank.

10. The heat exchange system of claim 6, wherein the aircraft controller is a Full Authority Digital Engine Control.

11. A heat exchange system for an aircraft comprising:

an aircraft controller for controlling an operation of an aircraft;

a thermoelectric device having a low temperature side and a high temperature side;

an aircraft controller loop comprising:

a first pump that circulates fluid through the low temperature side and the aircraft controller; and

a fuel loop comprising:

a second pump that circulates fuel from a fuel tank and through the high temperature side;

wherein heat is transferred away from fluid in the aircraft controller loop passing through the low temperature side to fuel in the fuel loop passing through the high temperature side.

12. The heat exchange system of claim 11, further comprising:

a control unit that provides an electrical signal to the thermoelectric device based on one or both of a temperature of fluid and a temperature of the aircraft controller.

13. The heat exchange system of claim 11, wherein the aircraft controller is a Full Authority Digital Engine Control.

\* \* \* \* \*